

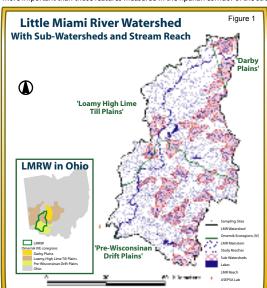
Landscape Influences on In-Stream Biotic Integrity: Use of macroinvertebrate metrics to identify landscape stressors in agricultural catchments.



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Abstract:

The biotic integrity of streams is influenced by quantitative and qualitative features in the landscape surrounding the catchment (Vannote, et.al, 1980). In this study, aquatic macroinvertebrate metrics (e.g., number or relative percentage of various groups such as Ephemeroptera, Plecoptera, or Trichoptera or EPT taxa, non-insects, oligochaetes, tolerant, intolerant, or facultative taxa, or Hilsenhoff's Biotic Index) were measured over three successive seasons (1999 - 2001) in 35 headwater streams (sub-watersheds) located in the Little Miami River (Ohio) watershed. These sub-watersheds are situated in one of three Omernik level IV ecoregions (Darby Plains, Loamy, High Lime Till Plains and Pre-Wisconsinan Drift Plains) and are characterized by variable land cover (e.g., 23-91% row crop agriculture), and geophysical characteristics (e.g., 27 - 36% soil clay content). Among the sub-watersheds, 16 are located in the Drift Plain, while the number situated in the Till and Darby are 15 and 4, respectively. We have used several approaches to examine the relationship of landscape features, of different types and different spatial scales, including geophysical (e.g., topography and soils) and cover (e.g., percent agriculture) and stressor gradients (e.g., reduced canopy cover, substrate embeddedness, and nutrient loads) influencing the water quality and biotic integrity of the streams they surround. In these sub-watersheds, some macroinvertebrate metrics appear to be influenced by various landscape features, at several spatial scales. In particular, land cover features measured at the catchment scale appeared more important than those features measured in the riparian corridor of the stream



Study Goal:

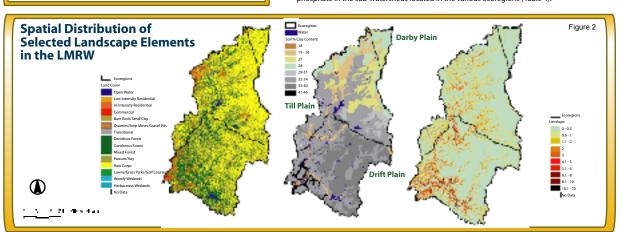
To examine the influence of surrounding landscape features (of various types and spatial scales) on the benthic macroinvertebrate communities in 35 tributaries (sub-watersheds) of the Little Miami River (LMR) watershed.

Study Area:

The LMR is a north-south orientated tributary of the Ohio River, draining a 5000 km² catchment in (Figure 1). Approximately, 97% of the LMR catchment is within three Omernik Level IV ecoregions, north to south, the Darby Plain, the Loamy, High Lime Till Plain (Till Plain), and the Pre-Wisconsinan Drift Plain (Drift Plain, Omernik et al., 1995). The Darby and Till Plains were graded by the Wisconsinan Glacier, the Drift was not, as a result these ecoregions provide a gradient of landscape features:

- Surface -- topographical relief: Darby ~ Till < Drift (Table 1 & Figure 2),
- Soil -- percent clay content: Darby > Till > Drift (Table 2 & Figure 2),
- Soil permeability: Darby ~ Till >> Drift (Table 2).
- Soil erodibility: Drift >> Till > Darby (Table 2). Land cover -- Row Crop; Drift > Till > Darby (Table 3
- Land cover -- Forest & Grass Drift > Till >> Darby (Table3)

Previously we have shown (Daniel et al., 2001), that these variations in landscape features result in significant differences in the observed water chemistry, including nutrients like nitrogen and $% \left(1\right) =\left(1\right) \left(1$ phosphate in the sub-watersheds located in the various ecoregions (Table 4).



Methods: ©

💀 Each LMR sub-watershed was sampled, via a kick net procedure (Klemm et al., 1998) to collect benthic macroinvertebrates over a 150 m reach (11 transects) at the pour point of during three consecutive summer low-flow periods (1999 - 2001 (Figure 1).

Invertebrates (composite from all habitat types) were identified to the lowest possible taxonomic level and forty-six invertebrate metrics were computed (Table 5), and the individual scores for each metric were averaged, by sub-watershed, over the three sampling years

Spatial Analysis was conducted using the ArcView Geographic Information System (GIS; ESRI, Redlands, CA) with all spatial data converted an Albers Conical Equal Area projection.

Grab samples for water chemistry were collected at multiple times over a three-year period and analyzed quarterly using USEPA Standard Methods (USEPA, 1979).

Statistical Procedures were conducted using Systat 10 software (SPSS, Chicago, IL). Spearman correlations were computed to examine the strength of the relationships between the invertebrate metrics and landscape metrics/water chemistry concentrations (p</= 0.05 considered significant). A one-way ANOVA (Boniferroni estimate of probabilities) was employed to compare the differences in the means of the metrics (both invertebrate and landscape) for the sub-watersheds in the 3 ecoregions. A step-wise discriminant analysis (DA) procedure was employed to compare the three ecoregions with respect to the overall pattern of the invertebrate metrics.

Dimensional Metric	Drift Mean	S.D.	Mean	Plain S.D.	Darby Mean	S.D.
Catchment Area (km²)	26.2	6.6	31.6	8.0	32.4	4.0
Catcht. Perimeter (km)	35.4	5.3	41.2	6.2	43.2	5.2
Reach Length (km)	66.2	19.7	74.4	40.0	48.9	5.1
Drainage Density (km ⁻¹)	0.8	0.3	0.6	0.3	0.6	0.2
Slope (%-mean-wgtd)	1.3	0.5	1.1	0.1	1.0	0.1

Watersheds Sorted B	y Ecore	gion (N	RC	S STAT	SGO Da	tabase)		
	Drift	Plain		Till I	Plain	Darby Plain		
Soil Metric	Mean	S.D.		Mean	S.D.	Mean	S.D.	
Erodibility (K-Factor)	0.423	0.004		0.361	0.013	0.349	0.012	
Permeability (in/hr)	0.19	0.10		0.68	0.16	0.79	0.12	
Clay Content (wgtd-%)	34.7	0.2		30.5	2.4	27.4	0.4	
Bulk Density (g/cc)	1.88	0.02		1.86	0.09	1.71	0.09	
Organic Content (wt-%)	0.48	0.02		0.56	0.23	0.38	0.26	

Drift Plain Till Plain Darby F	
Row Crop 44.8 12.7 68.9 17.6 87.2	S.D.
	3.7
Forested 21.1 9.2 8.3 6.7 3.3	1.6
Grassland 32.3 6.9 21.4 10.5 9.2	1.9
mpervious Surface 1.5 1.3 1.2 1.5 0.2	0.3
Netland 0.1 0.1 0.2 0.5 0.1	0.1
Inits = %; Color change indicates significance difference via ANOVA (p < 0.05).	

Table 4.Selected Water Chemistry From the LMR Sub- Watersheds, Measured in 1999 - 2001, Sorted By Ecoregion									
	Drift Plain			Till Plain			Darby Plain		
Analyte	Mean	S.D.	Mean S.D.				Mean	S.D.	
Total P	0.15	0.09		0.08	0.08		0.09	0.09	
Nitrate N	0.74	1.12		5.68	4.55		7.58	4.32	
Total Kjeldahl N	0.83	0.28		0.59	0.25		0.55	0.19	
Total Chlorides	32.65	13.98		42.04	19.81		25.73	6.78	
Total Sulfates	43.92	16.40		47.94	35.47		74.49	29.43	
Units = mg/L; Color change	Units = mg/L; Color change indicates significance difference via ANOVA (p < 0.05).								

Results & Discussion: •

Table 5.	List of the 46 Benthic N	Table 5. List of the 46 Benthic Macroinvertebrate Metrics Employed								
Metric Designation	Metric Definition	Metric Designation	Metric Definition							
EPTCHIR	Ephemeroptera/Chironomidae	P EPHM TX AV	% Taxa Ephemeroptera							
HBI AV	Hilsenhoff Biotic Index	P EPT IN AV	% Indiv EPT							
N CHIR IN AV	No. Indiv Chironomidae	P EPT TX AV	% Taxa EPT							
N CHIR TX AV	No. Taxa - Chironomidae	P FACL TX AV	% Taxa 4 < PTV < 6							
N EPHM IN AV	No. Indiv Ephemeroptera	P INTL TX AV	% Taxa PTV < 4							
N EPHM TX AV	No. Taxa Ephemeroptera	P MEGL IN AV	% Indiv Megaloptera							
N EPT IN AV	No. Indiv EPT	P MEGL TX AV	% Taxa Megaloptera							
N EPT TX AV	No. Taxa EPT Taxa	P NINS IN AV	% Indiv Non-Insecta							
N INTL TX AV	No. Taxa Chironomidae	P OLHI IN AV	% Indiv Oligochaeta & Hirudine							
N MEGL IN AV	No. Indiv Megaloptera	P PARA IN A	% Indiv Parasites							
N MEGL TX AV	No. Taxa Megaloptera	P PHRB IN AV	% Indiv Piercer-Herbivores							
N PLEC IN AV	No. Indiv Plecoptera	P PLEC IN AV	% Indiv Plecoptera							
N PLEC TX AV	No. Taxa Plecoptera	P PLEC TX AV	% Taxa Plecoptera							
N TOTL TX AV	No. Taxa Total	P PRED IN AV	% Indiv Predators							
N TRIC IN AV	No. Indiv Trichoptera	P SCAV IN AV	No. Indiv Scavengers							
N TRIC TX AV	No. Taxa Trichoptera	P SCRP IN AV	% Indiv Scrapers							
P CHIR IN AV	% Indiv Chironomidae	P SHRD IN AV	% Indiv Shredders							
P CHIR TX AV	% Taxa Chironomidae	P TOLR TX AV	% Taxa PTV>6							
P COFL IN AV	% Indiv Collector-Filterers	P_TRIC IN AV	% Indiv Trichoptera							
P COGA IN AV	% Indiv Collector-Gatherers	P TRIC TX AV	% Taxa Trichoptera							
P_D1TX IN AV	% Indiv Dominant Taxa	SDI_AV	Simpson Diversity Index							
P D5TX IN AV	% Indiv Dominant 5 Taxa	SWDI AV	Shannon-Weaver Diversity Index							
P_EPHM_IN_AV	% Indiv Ephemeroptera	T_INDV_AV	No. Total Individuals							
Each metric is the avera	iged value from three summer sa	ampling seasons (1999 -	2001) for each sub-watershed.							

community and landscape features was explored by examination of the Spearma correlation coefficients between the individual tebrate and landscape metrics (Table 6):

- Metrics based on numbers or percentages of organisms in the order *Ephemeroptera* (Mayflies) and certain tropic groups (e.g., piecer herbivores, collector-gatherers and shredders) showed most significant correlations with the largest number of landscape metrics, particularly those related to land cover.
- Other metrics, e.g., the total number of taxa, percent individuals in the order Trichoptera (caddisflies), individuals in dominant 5 taxa, or

Hilsenhoff's Biotic Index, were less responsive because they correlated with few

Some invertebrate metrics e.g., those based on the family of Chironomidae (midges), or the orders Megeloptera (dobsonflies and Plecoptera (stoneflies) or trophic groups such as parasites or collector-filterers were relatively unresponsive to the landscape

Table 6. Spea brate Metrics										Table 7. S	
			Lar	ndscape M	etric Cate	gory					
Invertebrate Metric	Catch- ment Dimen- sion	Catch- ment Slope	Catch- ment Soil	ment Land- cover	Riparian Land- cover	In-Stream Nutrients	Other	Sample Reach Metrics	Total	Metric	%
EDUM TY AV	2	6	7	45	0	1	2	1	47	P FORST	%
PHRB IN AV	ō	7	8	14	9	ō	- 5	4	47	R RCOFOR	R
EPT IN AV	3	- 6	6	- 11	9	3	3	3	43	PR FOREST	%
EPHM_IN_AV	2	4	7	-11	8	3	0	3	39	P CLAY	м
EPT TX AV	- 1	10	0	6	3	8	- 6	- 1	35	P_ROCRP	%
COGA_IN_AV	0	4	9	9	7	3	- 1	2	35	PR GRASS	%
EPT TX AV	0	- 5	2	12	- 8	3	- 1	4	35	NN_AV	N
EPHM_TX_AV	2	6	1	- 11	6	2	- 1	4	33	SO_KW	М
SHRD IN AV	1 2	2	6	6	- 4	2	2	1 3	32	TDKN_AV	Ē
EPT IN AV	2	6	9	0	9	0	2	3	33	N_BRIDG	N
PRED IN AV	4	0	9	7	2	3	3	3	31	SLP_WF	M
PTCHIR	1	2	6	8	- 5	2	2	3	29	SLP_W	M
TOTL TX AV	0	ñ	9	6	1	5	. 6	3	29	PERM_W	M
D5TX IN AV	1	Ö	7	4	2	- 8	- 5	2	29	TKN AV	T
INDV AV	- 1	4	7	- 8	- 5	3	0	- 1	29	PR ROWC	9
OLHI_IN_AV	0	- 8	0	- 5	- 6	- 5	- 1	3	28	P GRAS	9
BI AV	0	5	2	4	6	4	1	2	24	TSS AVG	T
TOLR TX AV	0	4	0	۰	0	13	- 5	2	24	DTP AV	T
TRIC IN AV	0	0	- 1	12	0	9	- 1	0	23	AM AV	A
SCAV IN AV	0	- 6		- 5	3	- 5	0	3	22	TP AV	T
WDI_AV	0	0	6	4	- 1	5	4	2	22	TVS AVG	T
TRIC TX AV	- 1	0	4	0	- 1	9	- 6	0	21	P IMPRV	%
CHIR TX AV	0	0	7	- 5	0	4	2	2	20	MW SLP3	М
DI AV	0	0	6	5	0	5	3 4	1	21 19	B DEN	М
INTL TX AV	0	0	0	1	0	6	7	0	19	RF4 KM	R
TRIC IN AV	0	0	1	0	0	10	1	0	12	RF3 KM	C
FACL TX AV	0	0	Ö	ő	0	8	1	3	12	DD RF4	R
TRIC TX AV	0	0	0	o	0	8	3	0	11	RBA AV	R
PLEC IN AV	0	2	1	0	4	2	0	0	9	MW SLP4	M
CHIR TX AV	0	0	0	0	0	7	1	0	8	SO AV	T
INTL_TX_AV	0	0	0	4	0	1	1	2	8	PR WATER	%
PLEC IN AV	0	2	1	1	2	2	0	0	8	TAN AV	T
SCRP_IN_AV	0	0	0	0	0	3	1	1	5	PLRF3	М
PLEC TX AV	0	2	1	0	1	1	0	0	5	FCOV AV	Ei
NINS_IN_AV	0	0	0	0	0	3	1	0	4	XR SLP	R
PLEC TX AV	0	0	1 0	0	3	0	0	0	4	P WETL	%
MEGL TX AV	0	0	1	0	0	1 0	0	1	2	CANP AV	c
MEGL TX AV	0	0	0	0	0	0	1	0	1	AR KM2	D
CHIR IN AV	1	0	0	Ö	0	0	0	0	1	PR KM	D
MEGL IN AV	0	0	0	0	0	0	0	1	-1	PLRF4	м
MEGL IN AV	0	0	Ö	ő	0	Ö	0	0	0	P ORM	м
PARA IN A	0	0	ő	ő	0	ő	0	0	0	PR IMPRV	9
otal	24	95	138	185	122	172	86	67	890	CL AV	Т

selected by the backward procedure

The list of the landscape metrics with significant correlations to invertebrate metrics is shown in Table 7. This chart ranks th various landscape metrics in order of those that showed significant correlations with the greatest number invertebrate metrics. A reach scale metric, % fines and sand (FNSA), appeared to be sending the strongest signal and was significantly correlated

This result is consistent with earlier work from our laboratory showing the importance of embeddeness in as a factor affecting invertebrate assembledges (Griffith et al., 2002)

Metrics related to land cover, particularly the percent forest cover (both catchment scale and the riparian corridor), also

Other land cover metrics (e.g., percent row crop and grassland), soil metrics (e.g., mean-weighted percent clay or soil rodibility), and the in-stream concentrations of nitrogen exhibited correlations with several of the invertebrate metrics.

Discriminant analysis (DA) using a step-wise backward selection (Figure 3, right panel) of the invertebrate metrics classified the sub-watersheds of the 3 ecoregions into unique sets around well-separated centroids The first factor (Fac B1) of the canonical scores plot, from the backward DA provides most of the separation and in turn

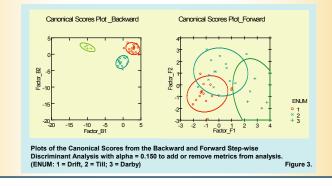
orrelates strongly with several classes of landscape metrics including: soil metrics, riparian landcover, in-stream nutrient and sulfate concentrations, and the reach metrics. The second, factor (Fac_B2), which provides less separation, and overall a weaker association with the landscape metrics

orrelates with total chlorides concentration, soil metrics, catchment landcover and nitrate-N concentration However, these results may be misleading because of the high correlation observed between the 17 invertebrate metrics

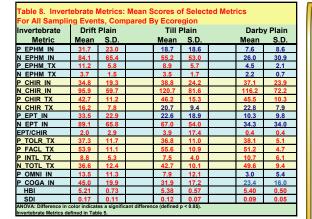
The use of a step-wise, forward selection DA procedure on the invertebrate metrics (Figure 3, left panel) produces a similar overall result but with less separation of the sub-watersheds by ecoregion

In the forward analysis, the sub-watersheds of the Drift and Darby ecoregions are separated but both also overlap with the

The forward DA is based on 7 invertebrate metrics with little covariance among the metrics. However like the backward DA Oth factors (Fac_F1 & Fac_F2) in the canonical scores plot, correlate with several landscape metrics



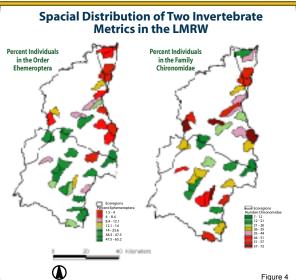
🖲 The second, factor (Fac_B2), which provides less separation, and overall a weaker association with the landscape metrics, correlates with total chlorides concentration, soil



To further compare the various invertebrate metrics scores across the three ecoregions, the metrics for sub-watershed in each ecoregion were averaged and tested (1-way ANOVA) for difference (Table 8). These results show:

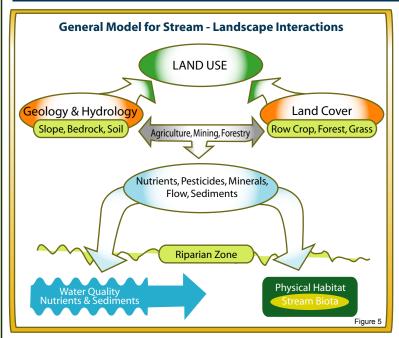
etrics based on Ephemeroptera (including EPT), the sub-watersheds in the Darby Plain ecoregion are significantly different from that metric in the Drift Plain, (and, in most cases, differed from those in the Till Plain as well; Table 8)

contrast, those metrics based on the more typically classified "tolerant" classes of organisms (e.g., Chironomidae family) showed no significant differences between the sub-watersheds of the three ecoregions (Table 8).



A comparison of the spatial distribution of the Ephemeroptera and Chironomidae metric scores for Percent Individuals within the LMR subwatersheds is shown in Figure 4.

• Conclusions: •



- Invertebrate communities in the streams draining the 35 sub-watersheds in this study are influenced by the combined effects of a variety of landscape influences including both natural (e.g., geophysical) as well as anthropogenic alterations such as land cover (Tables 6 & 7).
- The reach scale metric, substrate embeddedness (% Fines & Sand) was the most influential metric.
- are clearly different across the three ecoregions (Table 8).
- The overall relative values of all of the metrics in the various LMR sub-watersheds seem to result in metric values dependent on the ecoregion (Figure 3).
- A complete understanding these relationships between and scape signals and the invertebrate receptors however will be problematic, and require further analysis, due to the apparent complex inter-relationship between the various classes of landscape features. This concept is illustrated in
- Geophysical aspects of the landscape (e.g., hydrology, edrock geology, soils and topography) are key drivers determining land use and thus, landcover. A the same time, however, the landscape influences deriving from land use (e.g., nitrogen from agriculture) are transported through, and modulated by the soils, topography and other physical

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